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ICE 322 Control Engineering
Week 1

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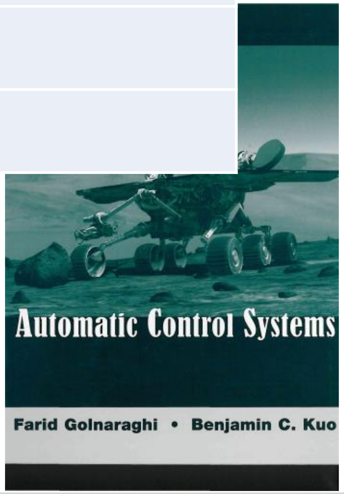
"Successful and unsuccessful people do not vary greatly in their abilities. They vary in their desires to reach their potential." – John Maxwell

• About the Course

Part I: COURSE INFORMATION			
Semester	462	Academic Year	2024- 2025
Department	EE	Specialization	/EEN/ICE
Course Title	Control Engineering		
Course Code	ICE 322	Pre-requisite	MATH 222 - Differential Equations and Linear Algebra
Credit Hours	3	Semester Effective Learning Hours	150
Weekly Contact Hours	LT	LB	Total
	2	3	5



Textbooks :

1. Modern Control Systems, Richard C. Dorf, 12th Edition
2. Automatic Control Systems, Benjamin C. Kou & Farid Golnarraghi, Ninth Edition, John Wily & Sons
3. Modern Control Engineering, Katsuhiko Ogata, 5th Edition

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• Course Semester Plan

D. Students Assessment Activities

No	Assessment Activities *	Assessment timing (in week no)	Percentage of Total Assessment Score
1.	Quiz 1	5/6	10%
2.	Quiz 2	11/12	10%
3.	Assignment	13-15	5%
4.	Midterm Exam LT	8	15%
5.	Final Exam LT	17-19	30%
6.	Lab Assignment 1	6/7	5%
7.	Lab Assignment 2	9/10	5%
8.	Lab Reports	11-14	5%
9.	Final Exam LB	16	15%

*Assessment Activities (i.e., Written test, oral test, oral presentation, group project, essay, etc.).

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Course Semester Plan

Part V (a): Weekly Pacing Schedule - Theory	
Week No.	**Topic and Sub-Topic**
1.	**Introduction to the course**
2.	**Introduction to Control Engineering:** Terminology and definitions of control systems, open and closed loop control, Examples of open & closed-loop control systems.
3.	**Mathematical Foundation**: Laplace Transform, Properties and examples
4.	**Mathematical Foundation**: Transfer Function & Impulse response, Introduction to MATLAB package use.
5.	**Block Diagram & Signal Flow Graph**: Block reduction, Signal Flow graph and Mason Rule (Gain Formula), State Diagrams, and Transformation to Transfer Functions and to State Space.
6.	**Modeling of Physical Systems:** Electrical Circuits, Mechanical Systems with Examples. **Quiz 1**
7.	**Modeling of Physical Systems:** Electromechanical Drives, Sensors, Encoders, Gears, Linearization, and Approximations with Examples.
8.	**Midterm Exams**
10.	**Time Domain Analysis of Control Systems:** Introduction to State Variables, Motivation and State Selection, State and Output Equations, Relationship between State Space and Transfer Function, State Equation Solution.
11.	**Stability Analysis of Linear Control Systems:** Concept of Stability, Stability & Asymptotic Stability, BIBO Stability Analysis.
12.	**Stability Analysis of Linear Control Systems:** Stability Analysis, Definition of Stability and Robustness, Routh-Hurwitz Criterion. Examples.**Quiz 2**
13.	**Time Domain Analysis of Control Systems**: Test Signals, Impulse & Unit Step Response, Transient Response of second order systems, Types of Systems, Design examples.
14.	**Root Locus Technique:** Introduction**,** Motivation, Terminology and definition, Evans Rules, Root Locus Technique, Application Examples, Design Examples.
15.	**Frequency Domain Analysis** Nyquist and Bode Techniques, Short Summary and ideas for application. **Design Of Control Systems** Design with PD, PI & PID controller
16.	**Final Theory Exams**
17.	**Final Theory Exams**

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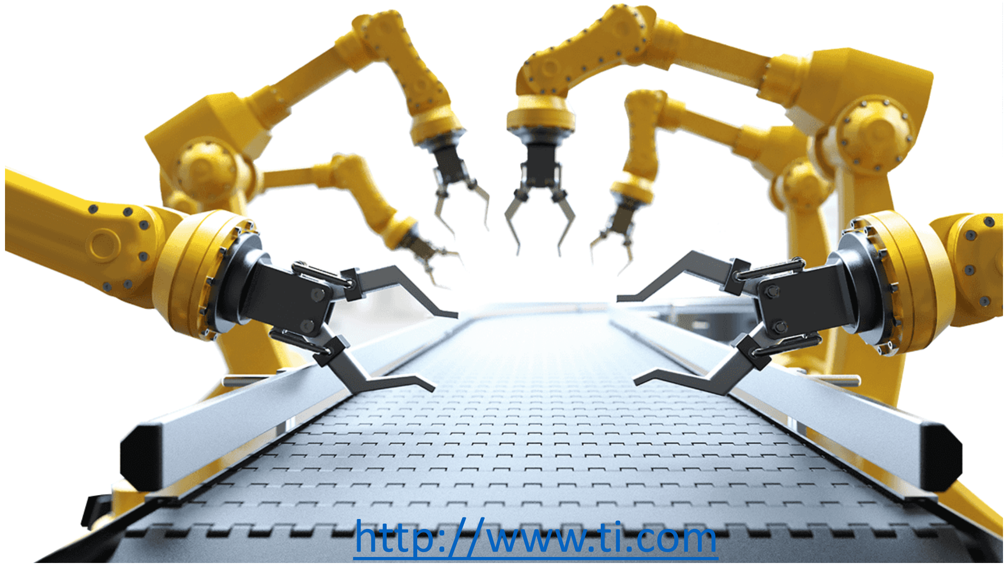
The main **Objectives** of this chapter are:

1. To **Define A Control System**.
2. To explain why **Control systems are important.**
3. To introduce the **Basic Components** of a control system.
4. To give some examples of control-system applications.
5. To explain why **feedback** is incorporated into most control systems.
6. To introduce **Types of control**



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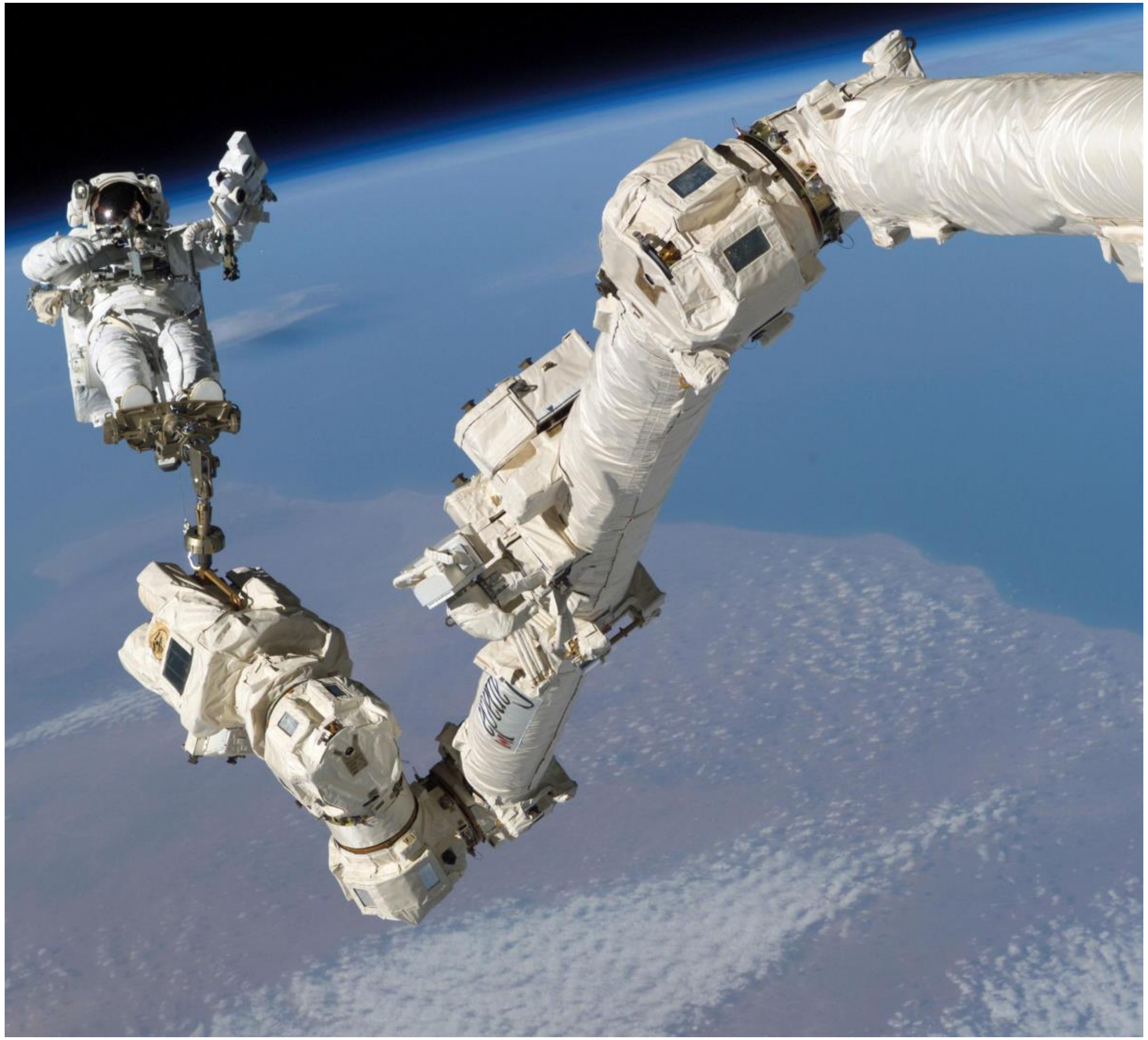
Introduction

- Why Control?
- What is a Control System? why **Control systems are important.**
- Manual VS Feedback control.
- Real Applications and Examples.
- **Basic Components** of a control system.
- **Types of control**



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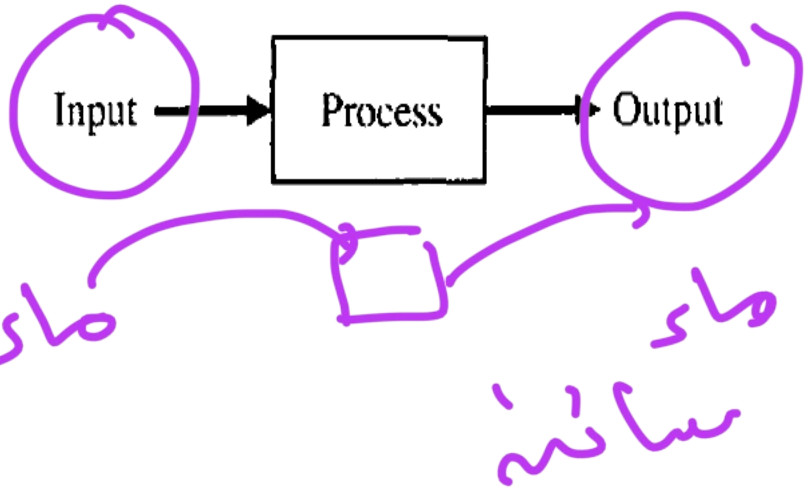
1.1 Introduction to Control Systems

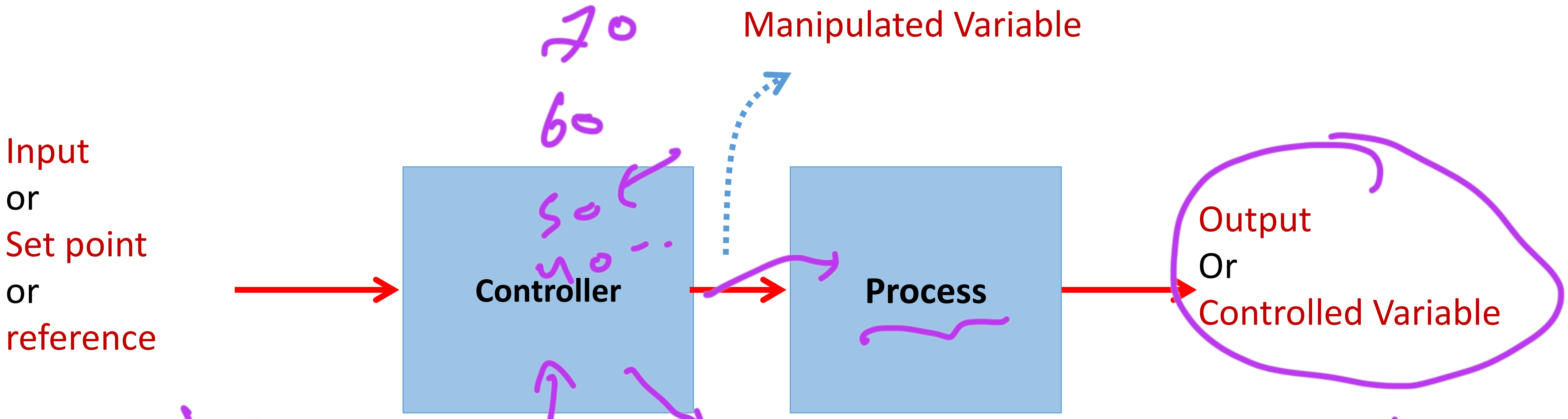
- A **control system** is an interconnection of components forming a system configuration that will provide a desired system response.

- Cause-Effect relationship

FIGURE 1.1
Process to be controlled.

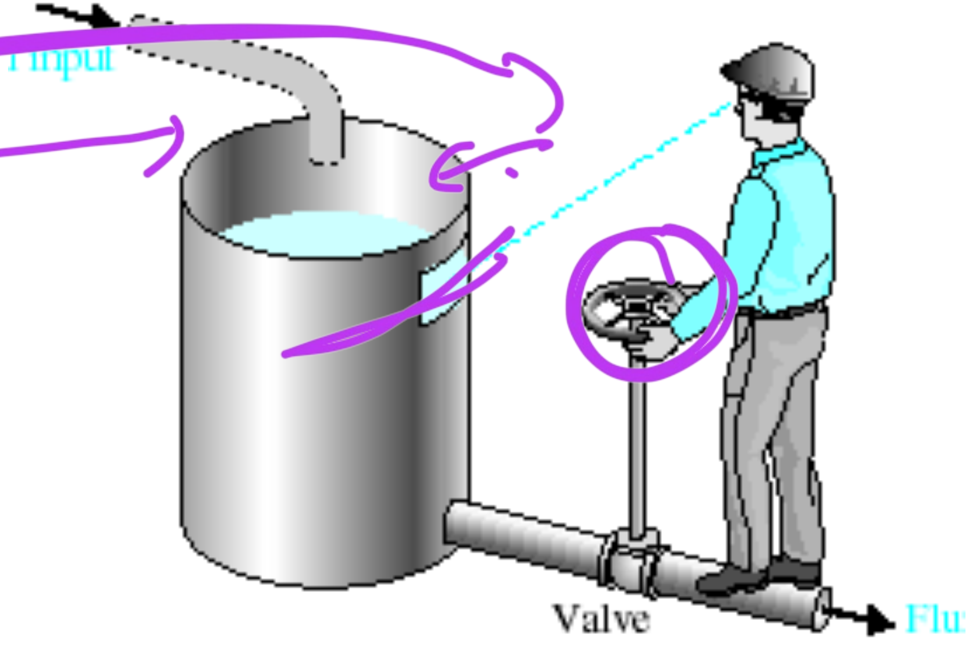


Basic Terminology

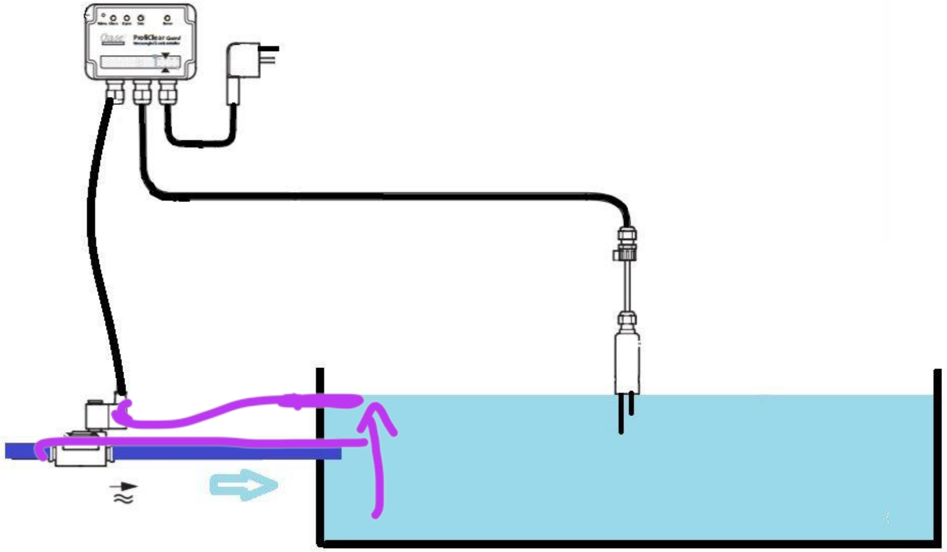


Types of Control

- **Manual Control Systems**
  - ➢Light of the class
  - ➢Water Level Control by operator



- **Automatic Control System**
  - ➢Room Temperature regulation Via A.C
  - ➢Human Body Temperature Control



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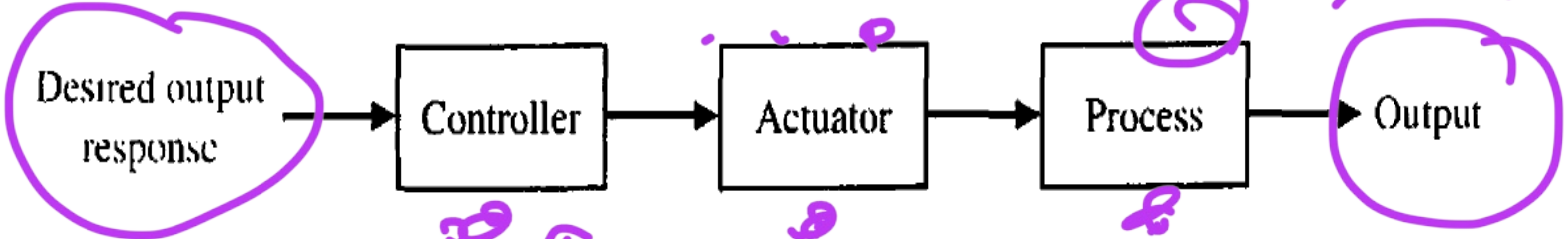
Types of Control

- **An open-loop control system** utilizes an actuating device to control the process directly without using feedback.

FIGURE 1.2
Open-loop control system (without feedback).



Advantages:
1) Simple
2) Fast response

Disadvantages:
1) May not be able to eliminate static error
2) Sensitive to disturbance, model mismatch and parameter variation.

Types of Control

- A **closed-loop control system utilizes an additional measure (feedback)** of the actual output to compare the actual output with the desired output response.
- Closed-loop control has many advantages over open-loop control including the ability to reject external **disturbances** and improve **measurement noise** attenuation, Increase stability margin, increase robustness
- Disadvantages:
- More expensive, more complicated system and may not be as fast as the open loop

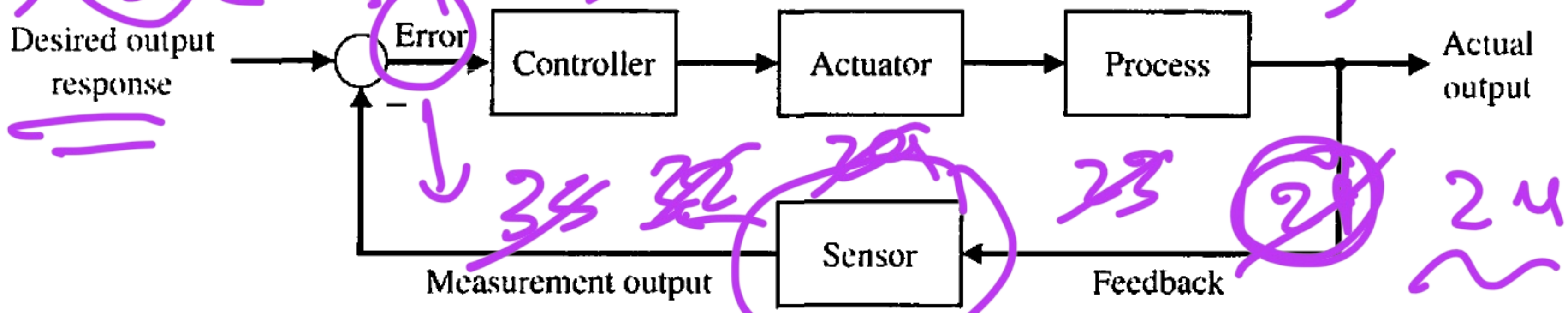


FIGURE 1.3 Closed-loop feedback control system (with feedback).

A. Comparison of open-loop and closed-loop control systems is given in the following table:

Open-loop control systems	*Closed-loop control systems*
1. Inaccurate and unreliable.	1. Accurate and reliable.
2. Consume less power.	2. Consume more power.
3. Simple and economical.	3. Complex and costlier.
4. The changes in output due to external disturbances are not corrected automatically.	4. The changes in output due to external disturbances are corrected automatically.
5. They are generally stable.	5. Efforts are needed to design a stable system.

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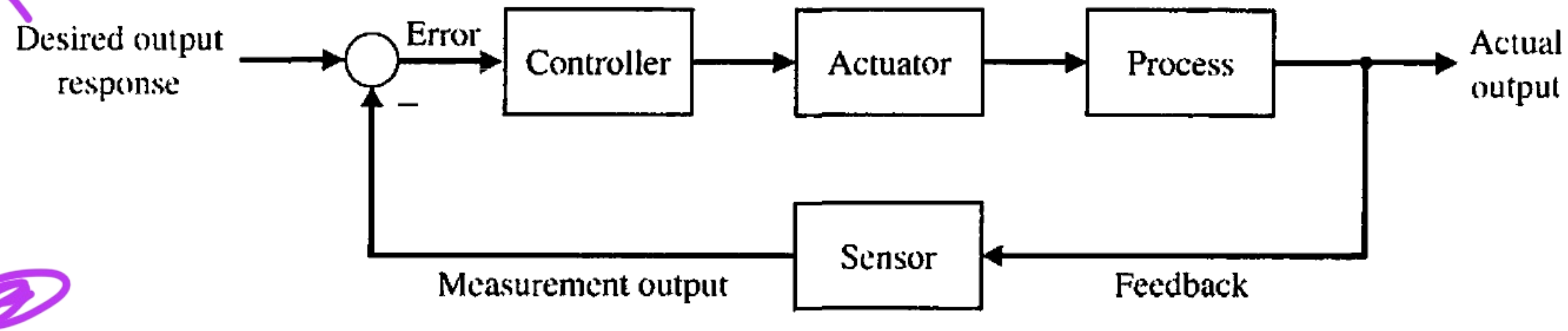
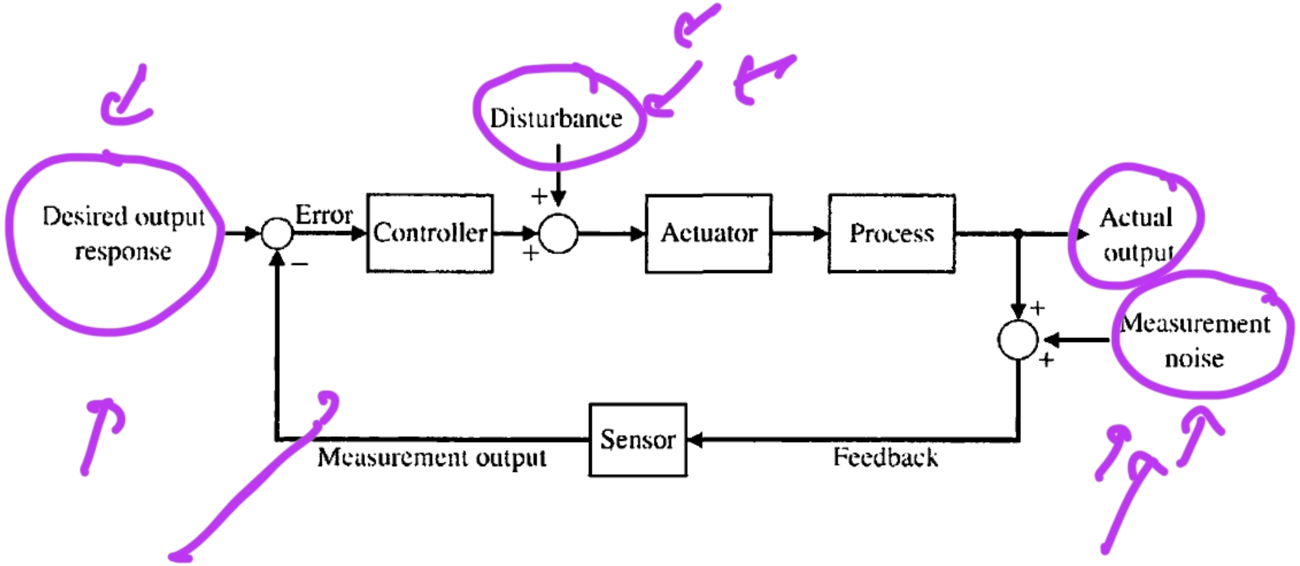
Types of Control

- **A closed-loop control system** **<u>utilizes an additional measure (feedback)</u>** of the actual output to compare the actual output with the desired output response.
- Closed-loop control has many advantages over open-loop control including the ability to reject external **disturbances** and improve **measurement noise** attenuation.

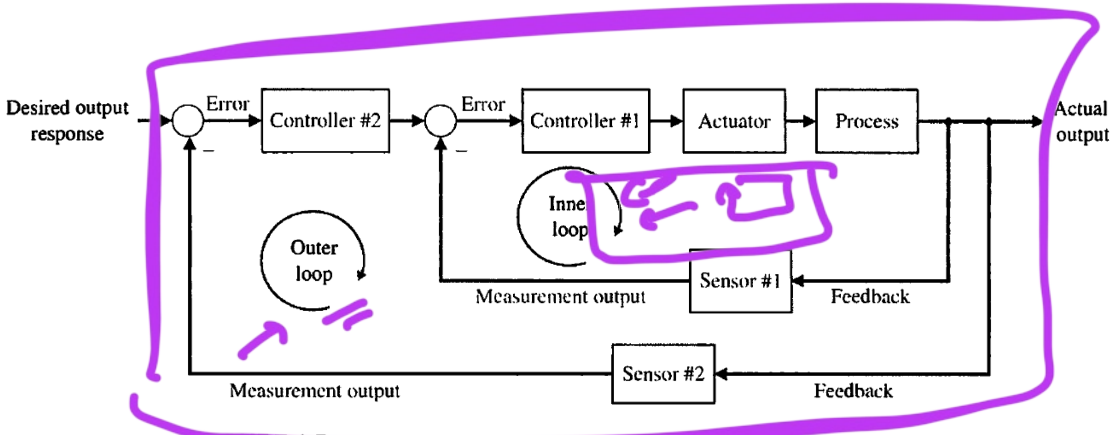
FIGURE 1.3
Closed-loop feedback control system (with feedback).



- ❑ **External disturbances and measurement noise are inevitable in real-world** applications and must be addressed in practical control system designs.



- ❑ A common **multiloop feedback control system** is illustrated in Figure 1.5 with an inner loop and an outer loop.
  - In this scenario, the inner loop has a controller and a sensor and the outer loop has a controller and sensor.



loop and an outer loop.

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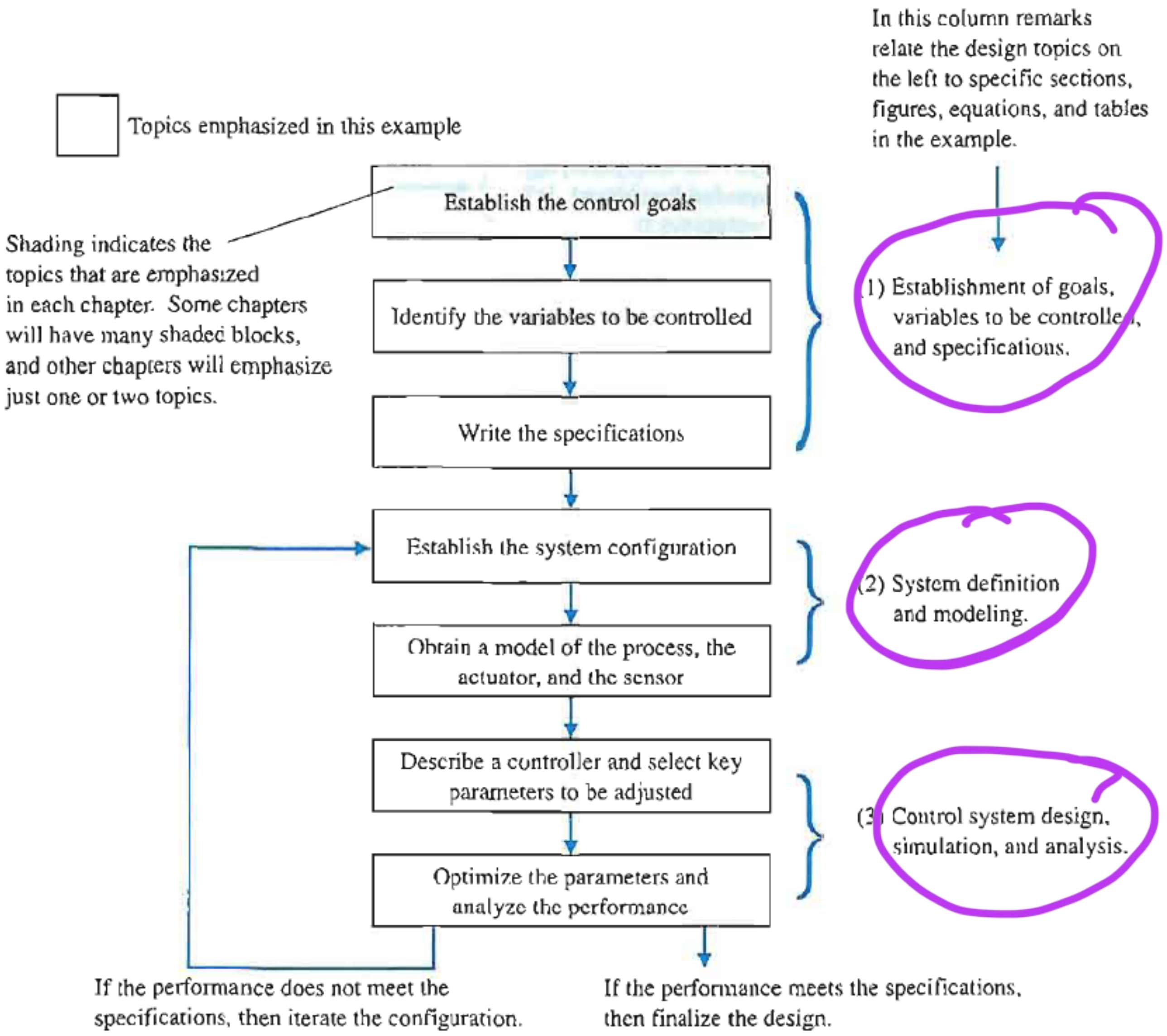
In this column remarks relate the design topics on the left to specific sections, figures, equations, and tables in the example.
Topics emphasized in this example
Shading indicates the topics that are emphasized in each chapter. Some chapters will have many shaded blocks, and other chapters will emphasize just one or two topics.
Establish the control goals
Identify the variables to be controlled
Write the specifications
Establish the system configuration
Obtain a model of the process, the actuator, and the sensor
Describe a controller and select key parameters to be adjusted
Optimize the parameters and analyze the performance
(1) Establishment of goals, variables to be controlled, and specifications.
(2) System definition and modeling.
(3) Control system design, simulation, and analysis.
If the performance does not meet the specifications, then iterate the configuration.
If the performance meets the specifications, then finalize the design.

Example of control system applications

1. **Smart Transportation System** e.g. Intelligent cars having maximum comfort, safety and fuel efficiency. They have climate control, antilock break system e.t.c.
2. **Intelligent Systems** e.g. robotics, material handling, biomedical, marine and defense.
3. **Steering Control of Automobile** e.g. Steering of an automobile.

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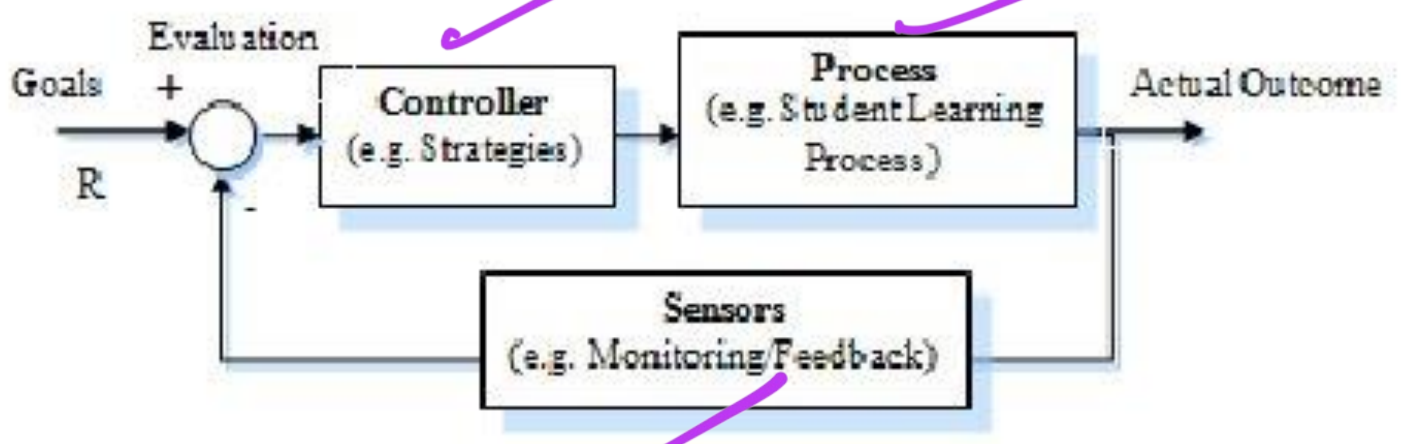
Questions and Answers

1. List the advantages and disadvantages of closed Loop system.

2. What are the main components of a control system?

3. Construct a feedback model of the learning process between the students and teacher ?



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Cont. Questions and Answers

1. In an open loop control system :
(a) Output is independent of control input
(b) Output is dependent on control input
(c) Only system parameters have effect on the control output
(d) None of the above

2. A good control system has all the following features except
(a) good stability
(b) slow response
(c) good accuracy
(d) sufficient power handling capacity

3. A car is running at a constant speed of 50 km/h, which of the following is the feedback element for the driver?
(a) Clutch
(b) Eyes
(c) Needle of the speedometer
(d) Steering wheel
(e) None of the above

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Cont. Questions and Answers

1. In an open loop control system :

(a) Output is independent of control input

(b) Output is dependent on control input

(c) Only system parameters have effect on the control output

(d) None of the above

Ans: a

2. A good control system has all the following features except

(a) good stability

(b) slow response

(c) good accuracy

(d) sufficient power handling capacity

Ans: b

3. A car is running at a constant speed of 50 km/h, which of the following is the feedback element for the driver?

(a) Clutch

(b) Eyes

(c) Needle of the speedometer

(d) Steering wheel

(e) None of the above

Ans: c

Boiler system

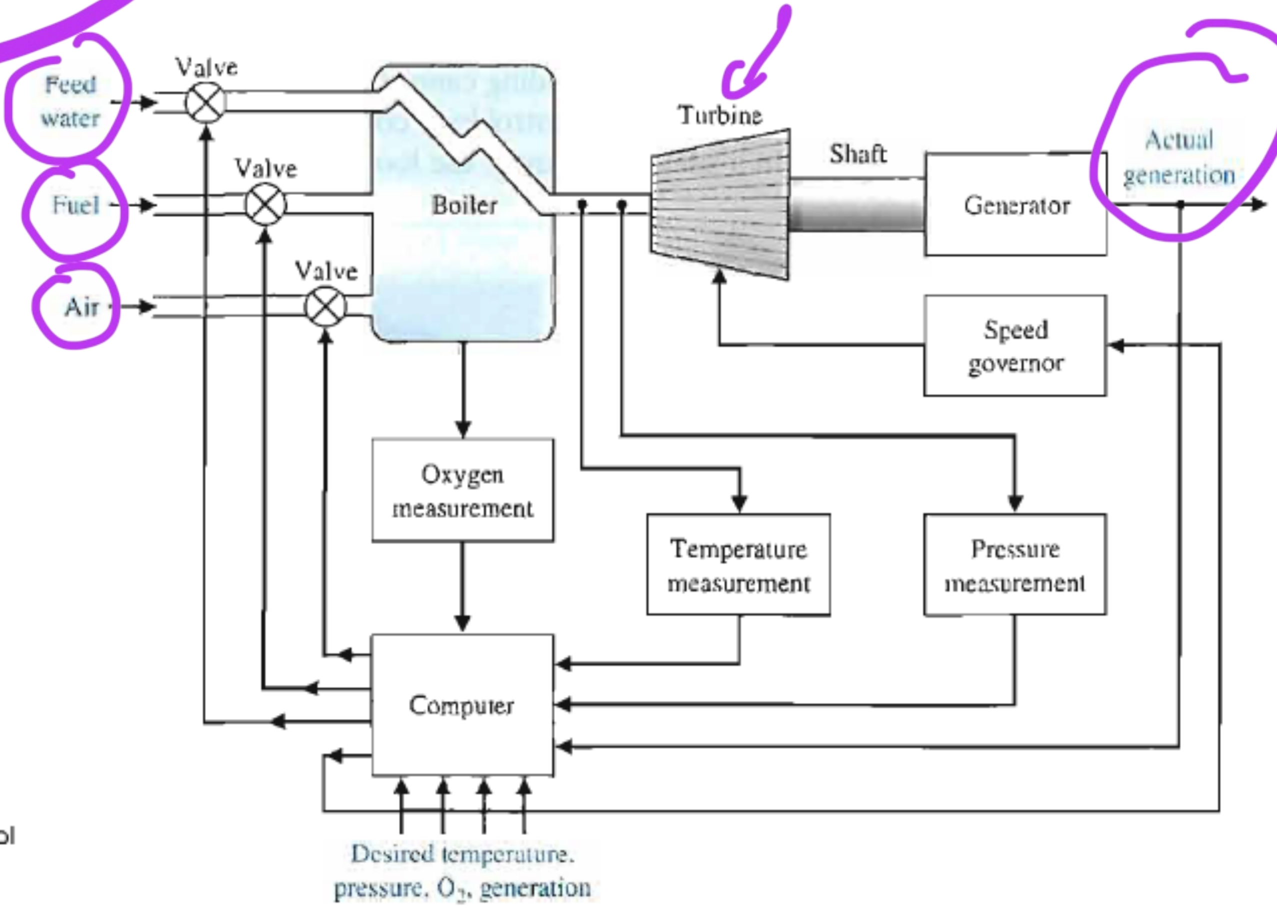
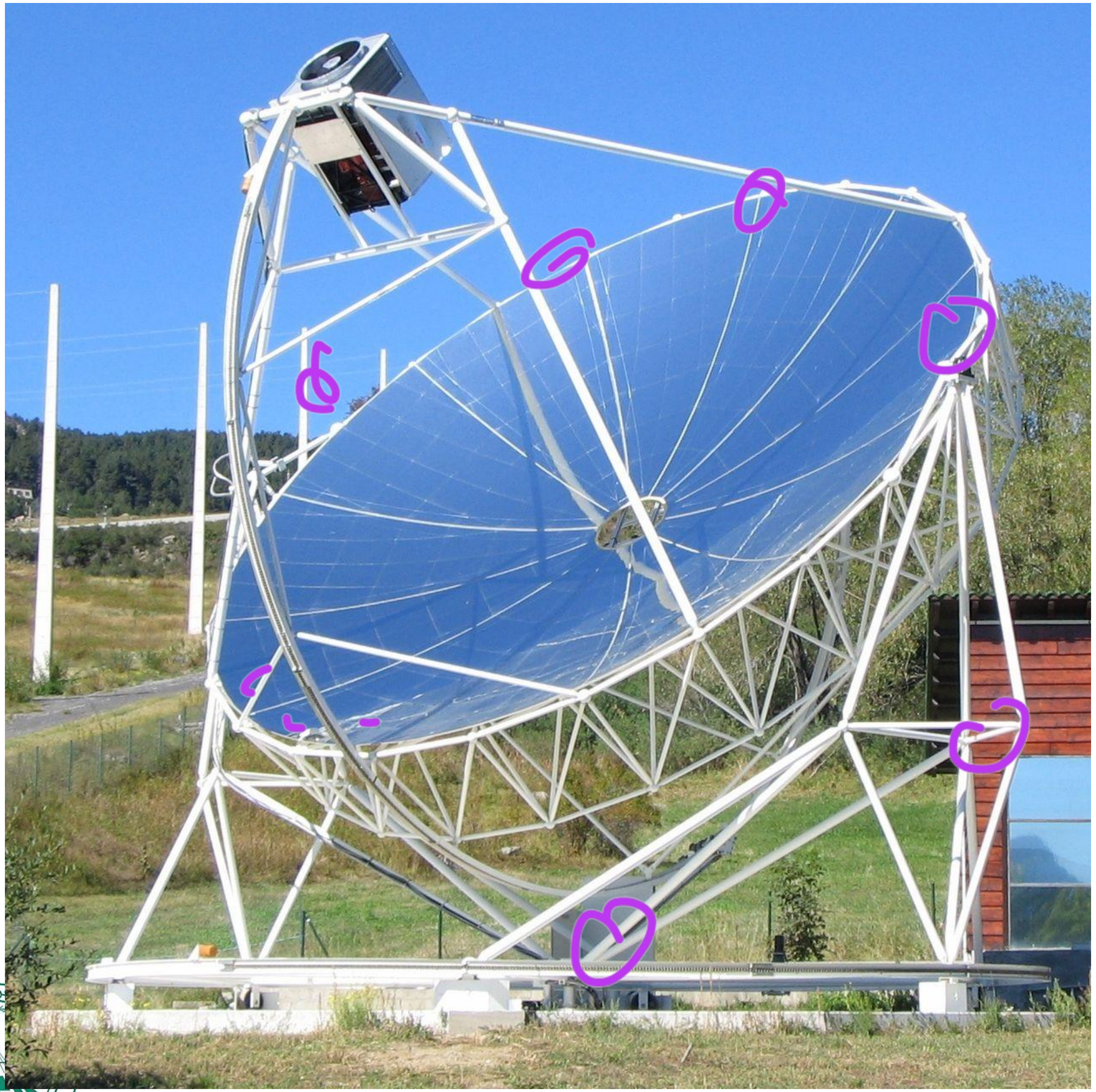


FIGURE 1.11
Coordinated control system for a boiler–generator.



Example:

Sun-Tracking Control of Solar Collectors

- One of the most important features of the solar collector is that the collector dish must track the sun accurately. Therefore, **the movement of the collector dish must be controlled by sophisticated control systems.**

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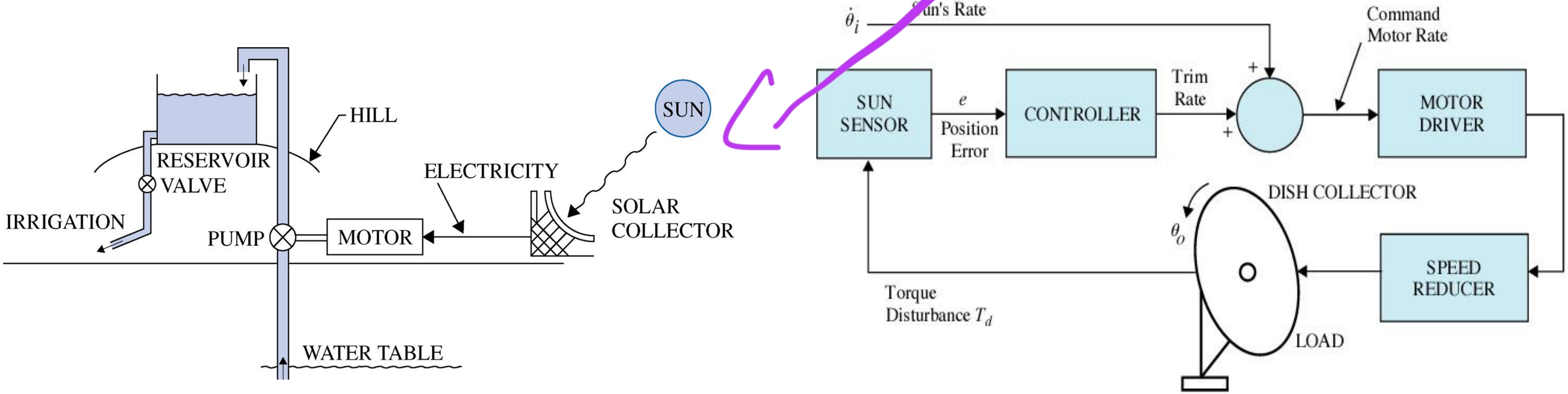
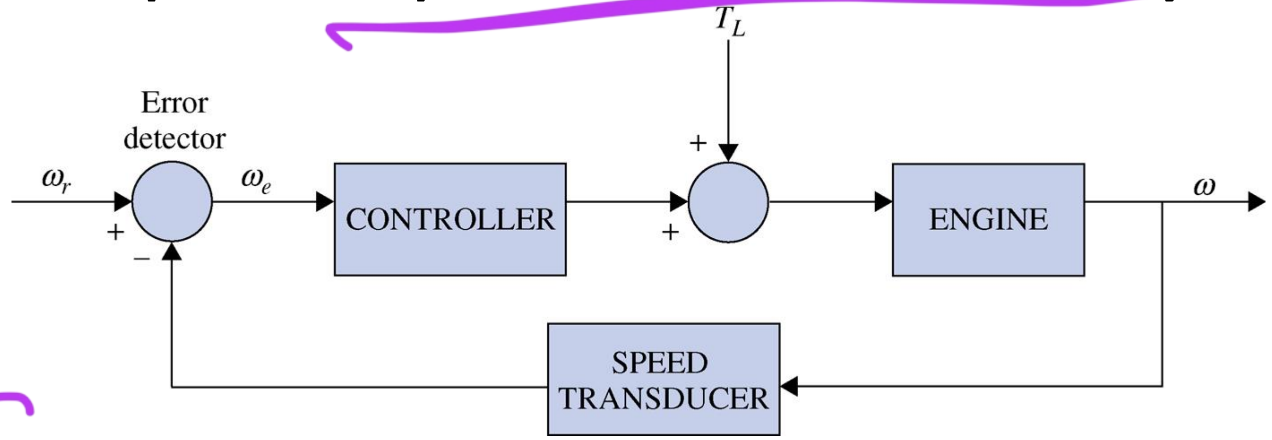
Cont. Examples:
Sun-Tracking Control of Solar Collectors



Cont. Examples:
Response of the open-loop idle-speed control system



A closed-loop idle-speed control system is shown in Fig. 1-7. The reference input ω_r sets the desired idling speed. The engine speed at idle should agree with the reference value ω_r, and any difference such as the load torque T_L is sensed by the speed transducer and the error detector. The controller will operate on the difference and provide a signal to adjust the throttle angle α to correct the error. Fig. 1-8 compares the typical performances of open-loop and closed-loop idle-speed control systems. In Fig. 1-8(a), the idle speed of the open-loop system will drop and settle at a lower value after a load torque is applied. In Fig. 1-8 (b), the idle speed of the closed-loop system is shown to recover quickly to the preset value after the application of T_L.

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Cont. Examples:
Response of the open-loop idle-speed control system

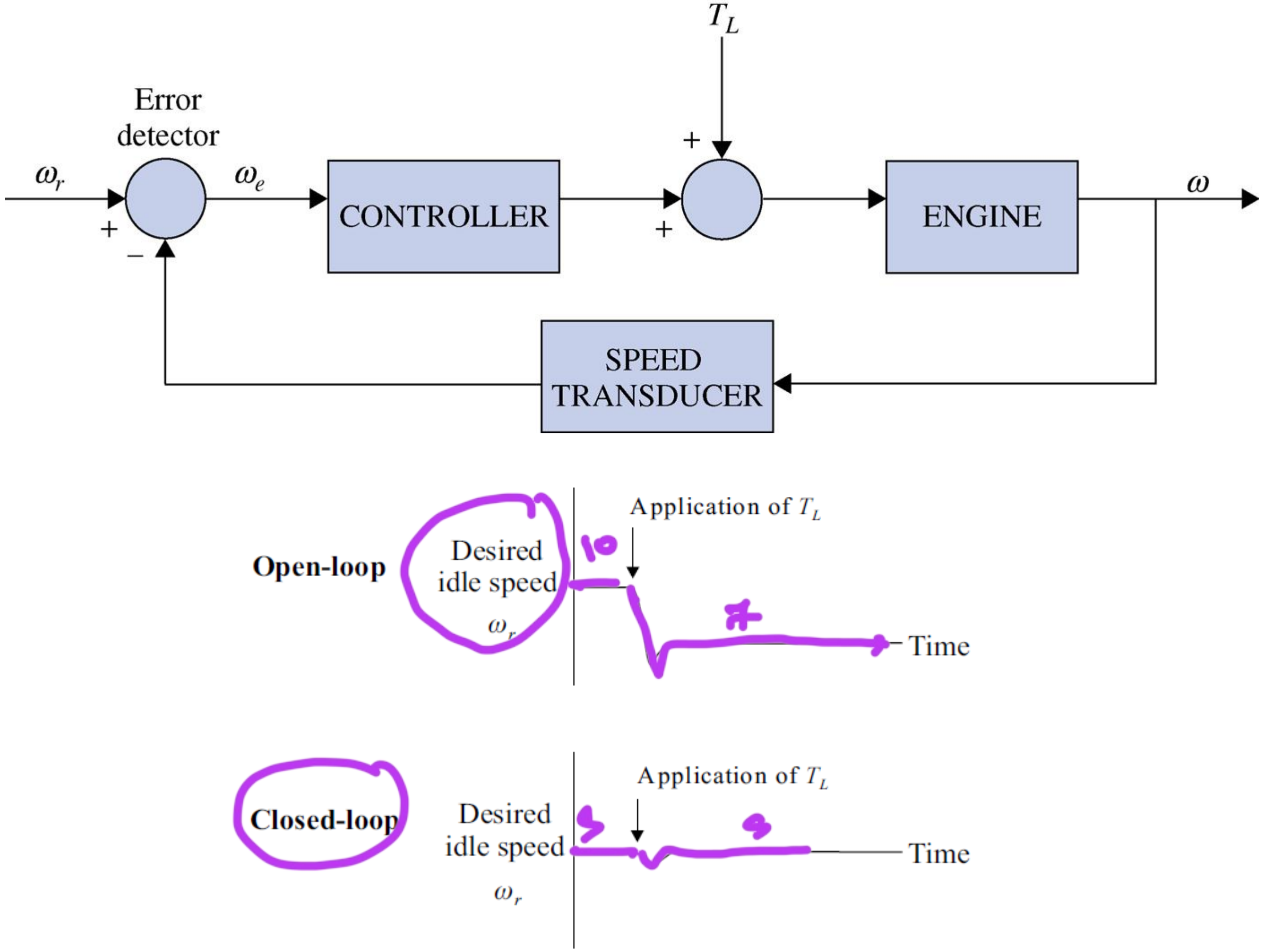

Fig 1-10 Typical response of the open-loop idle-speed control system.

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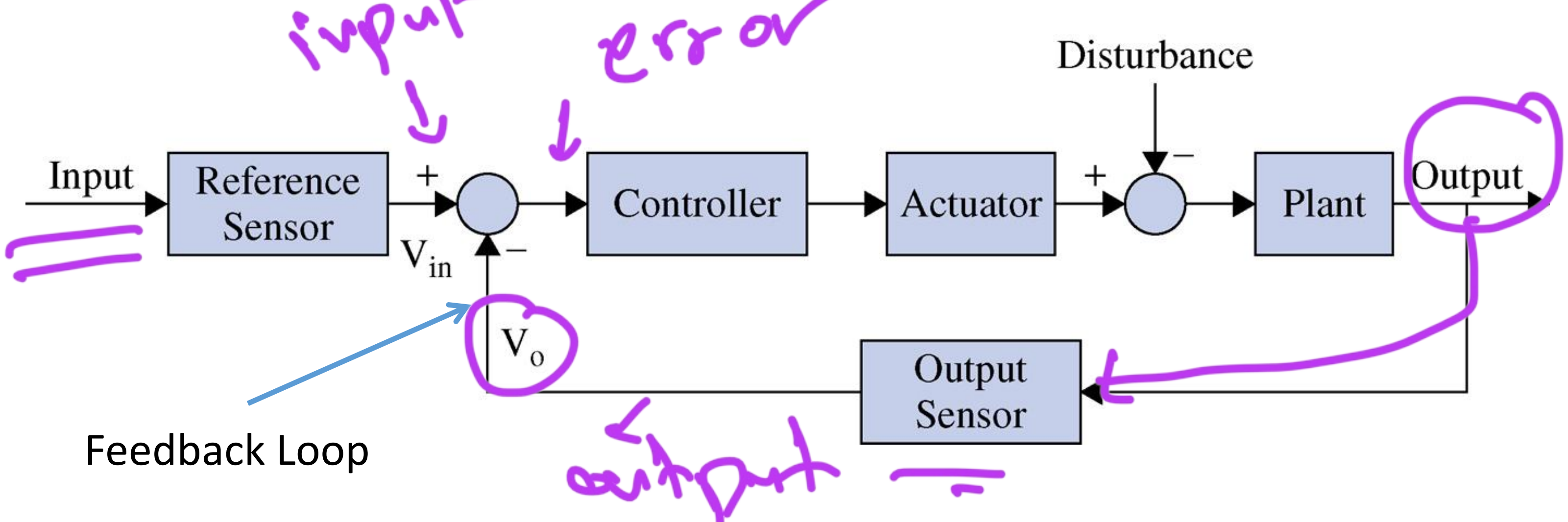
Cont. Examples:
Response of the open-loop idle-speed control system

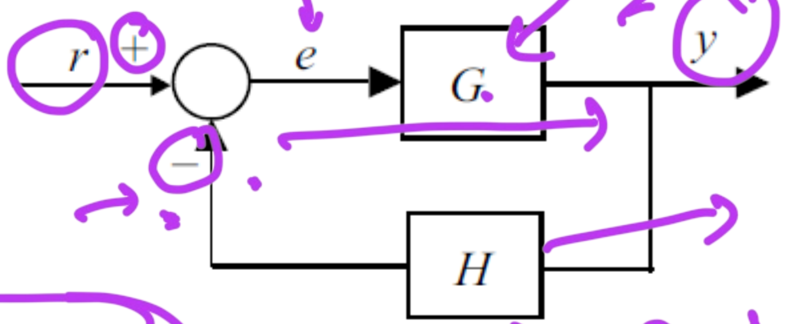
- Feedback is used to reduce the error between the reference input and the system output.
- Feedback also has effects on such system performance characteristics as stability, bandwidth, overall gain, impedance, and sensitivity.



Block diagram representation of a general control system.

Cont. Examples:

Effect of feedback on control systems



If $H = 0 \Rightarrow$ open loop system.

The input-output relation is

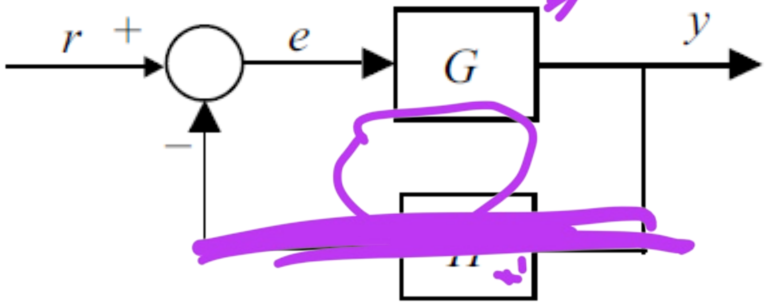
$$M = \frac{y}{r} = \frac{G}{1 + GH}$$

- Feedback may increase the gain in one frequency range but decrease it in another.

Cont. Examples:
Effect of feedback on overall gain:

open-loop gain $= G$

closed-loop gain $= \dfrac{G}{1 + GH}$



Effect of feedback on stability:

If GH = -1, the system becomes unstable.

Feedback can improve stability or be harmful to stability if it is not properly applied.

Cont. Examples:

- A Good Control System should be insensitive to noise or disturbance and sensitive to input commands.
- **Examples are:** Thermal noise voltage in electronic circuits; Brush or commutator noise in electric motors
- External disturbances include wind gust on antenna
- **Feedback can reduce the effect of noise.** (in general)

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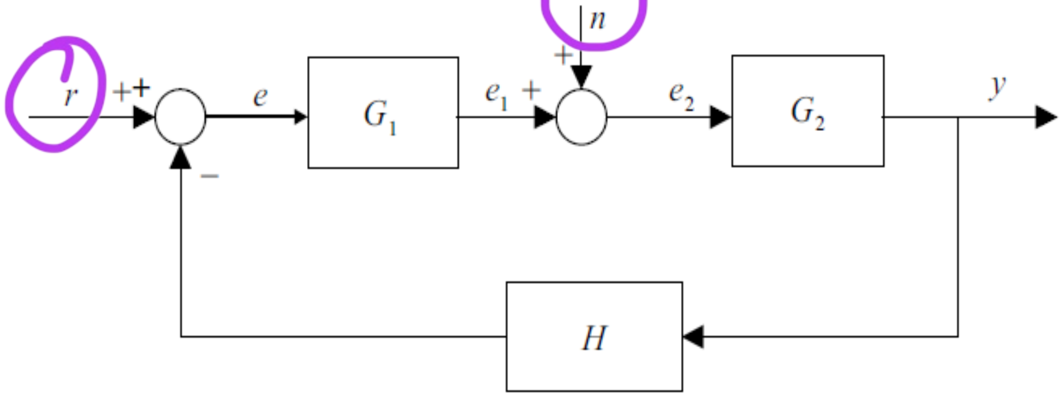
Cont. feedback system

superposition

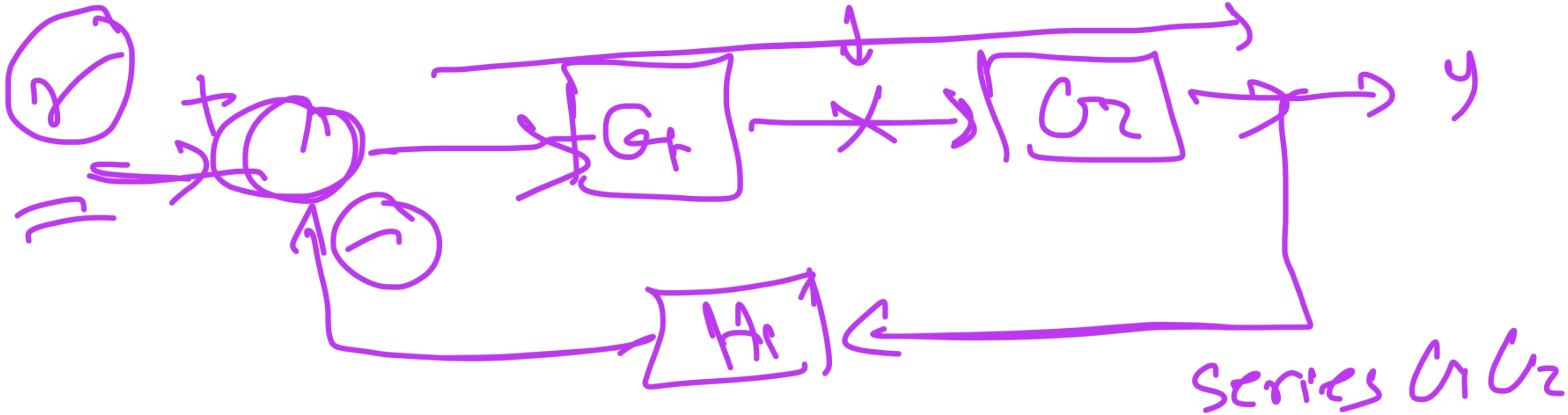


Open loop system:

$$H = 0 \quad \Rightarrow \quad y = G_1 G_2 e + G_2 n, \qquad e = r$$

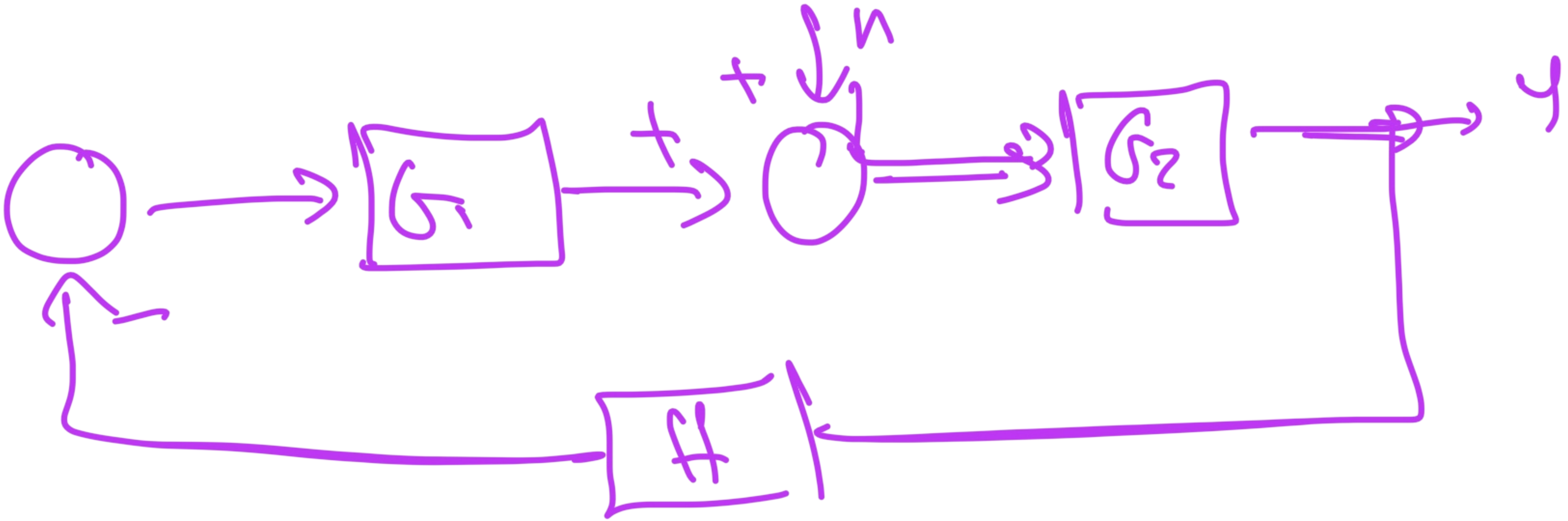
Closed-loop system:

$$y = \frac{G_1 G_2}{1 + G_1 G_2 H} r + \frac{G_2}{1 + G_1 G_2 H} n$$



$$\frac{y}{r} = \frac{G_1 G_2}{1 + G_1 G_2 H}$$

$$y = \frac{G_1 G_2}{1 + G_1 G_2 H} \rightarrow$$



$$\frac{y}{n} = \frac{G_2}{1 + G_1 G_2 H}$$

منفی

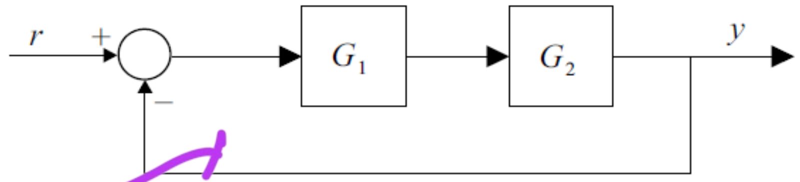
$$\frac{y}{c(s)} = \frac{G_1 G_2}{1+G_1G_2H} r + \frac{G_2}{1+G_1G_2H} n$$

Type of feedback control system

Feedback control system can be classified in a number of ways depending upon the purpose of classification:

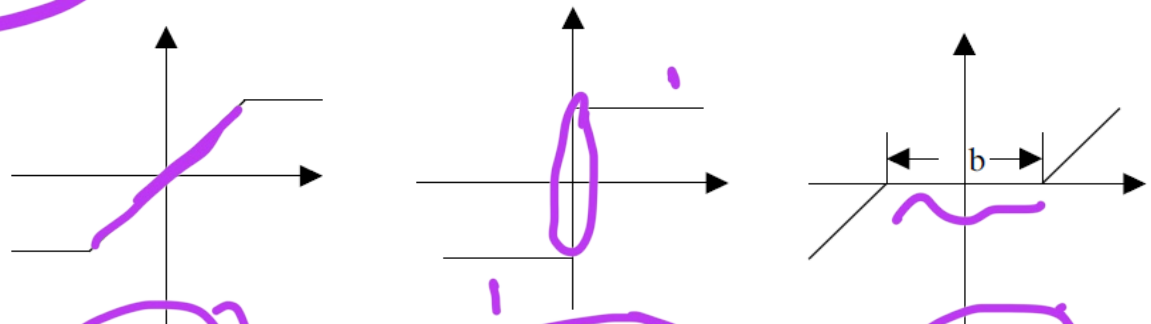
1) Linear and non-Linear control system

Linear:



- They strictly follows the Superposition and Homogeneous principle.
    - It means if x → yx → y then it also means kx → ky
    - and x1+x2→ y1+y2.

Nonlinear:



Saturation   Ideal relay   Dead band

Linear or non-linear Example

Example

Consider $y(u) = 5u$, *applying the principle of superposition*

$$\begin{aligned} 3y(u)+4y(u) &= 3 \times 5u + 4 \times 5u \\ &= 35u \end{aligned}$$

$$\begin{aligned} y(3u)+y(4u) &= 5 \times (3u) + 5 \times (4u) \\ &= 35u \end{aligned}$$

Since the system **obeys** *the principle of superposition, the system is* **linear**.

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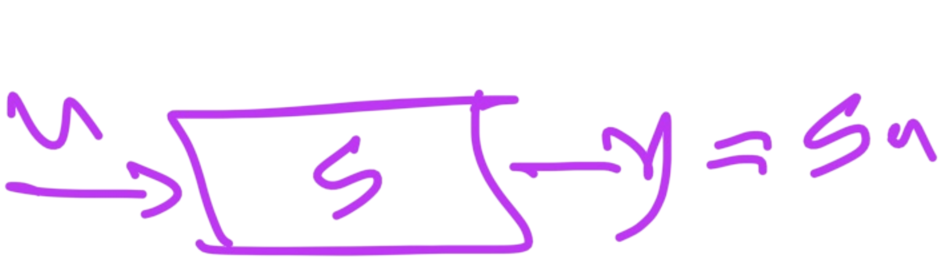
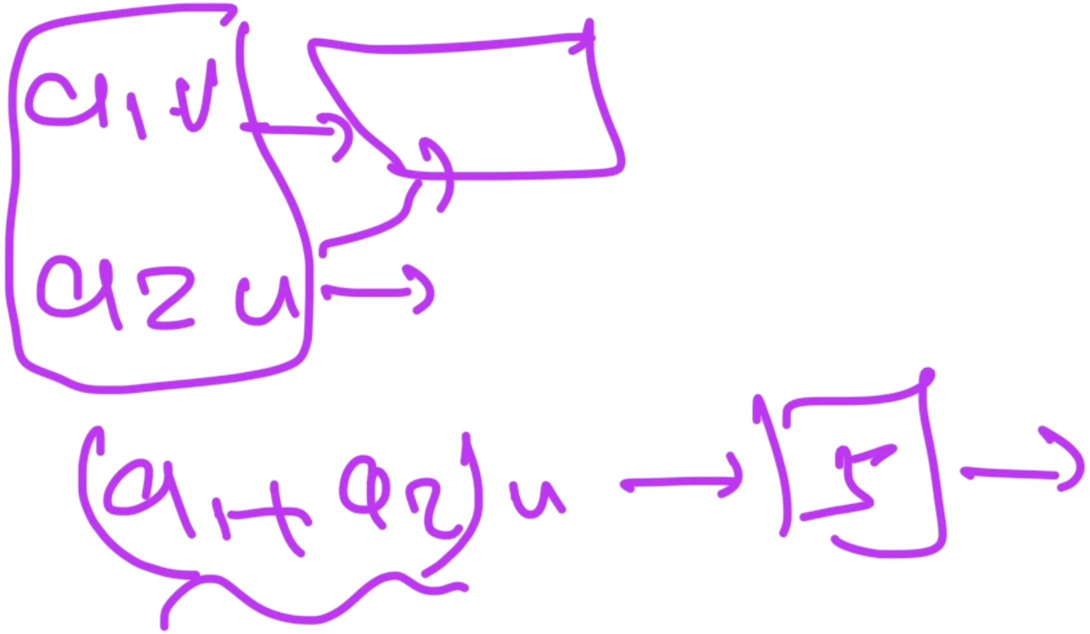
$$y = Su$$



$$y = Sa_1u + Sa_2u$$



linear

$$y = S(a_1 + a_2)u$$

Linear or non linear

Example

Consider $y(u) = 5u + 6$, *applying the principle of superposition*

$$3y(u) + 4y(u) = (3 \times 5u + 3 \times 6) + (4 \times 5u + 4 \times 6) = 35u + 42$$

$$y(3u) + y(4u) = (5 \times (3u) + 6) + (5 \times (4u) + 6) = 35u + 12$$

Since the system **does not** *obey the principle of superposition, the system is* **not linear**.

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$$y = 5u + 6$$

$$y_1 = 5(a_1 u) + 6$$

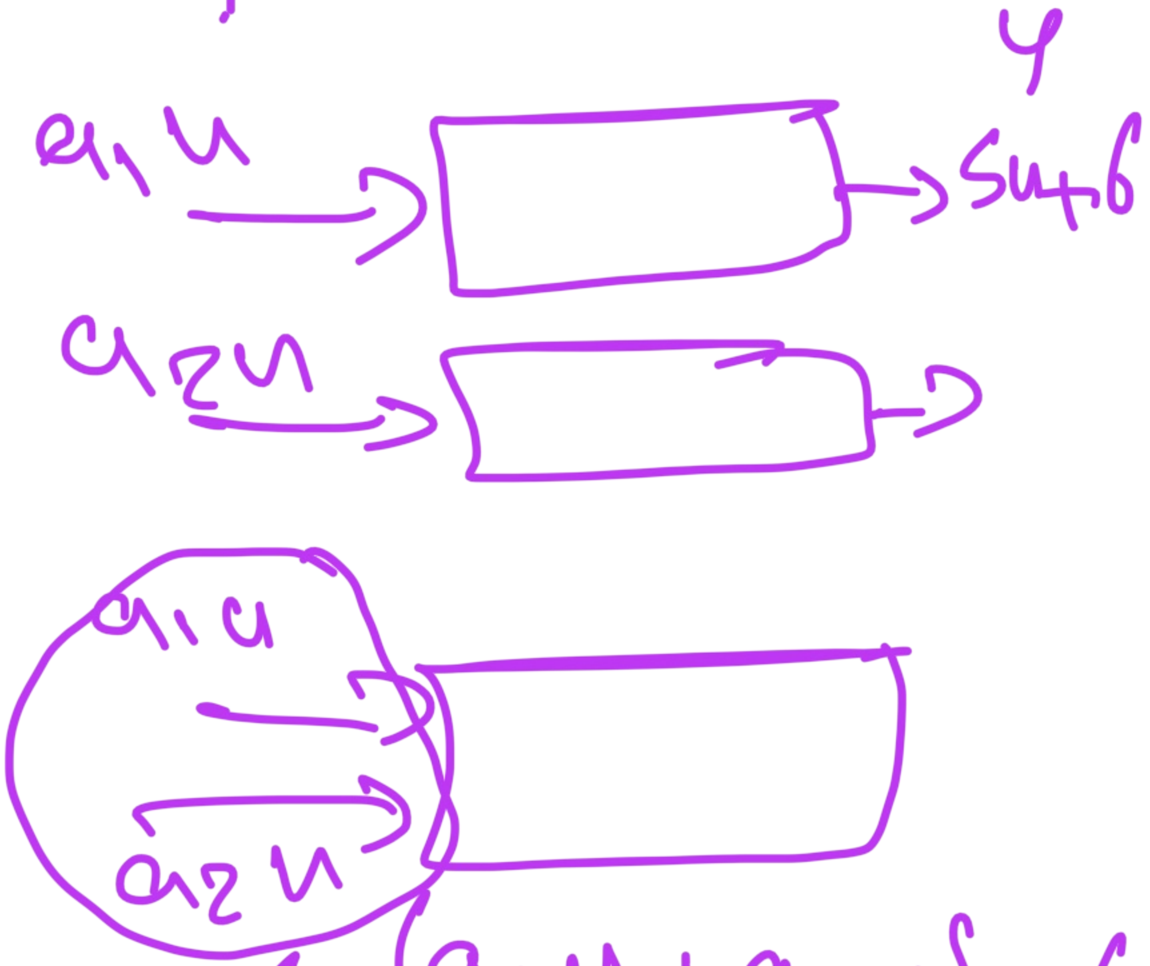
$$+ \quad y_2 = 5(a_2 u) + 6$$

$$y_1 + y_2 = 5a_1u_1 + 5a_2u + 12$$

$$\neq$$

$$5a_1u_1 + 5a_2u + 6$$

Non linear



$$5(a_1u + a_2u) + 6$$

Cont. Type of feedback control system

2) Time invariant vs. Time varying

Time invariant system: Parameters of a control system are stationary with respect to time during system operation.

Otherwise: Time varying systems

3) Continuous-data system: the signals at various part of the system are all functions of the continuous time variable t.

Discrete data system: the signals at one or more points of the system are in the form of either a pulse train or a digital code.

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21. Distinguish between linear and nonlinear control systems.

A. A linear control system is one for which the principle of superposition and the principle of homogeneity are valid and a nonlinear control system is one for which the principle of superposition and the principle of homogeneity are not valid.

22. State the principle of superposition.

A. The principle of superposition states that the response produced by the simultaneous application of two different forcing functions is equal to the sum of the two individual responses.

23. Distinguish between time-invariant and time-varying control systems.

A. A time-invariant control system is one in which the parameters of the system are stationary with respect to time during the operation of the system. Its output characteristics do not change with time and it can be represented by constant coefficient differential equations.

Review Questions:

- **Define external disturbance?**

- **State the effects of feedback on control systems? In terms of**
  - **Gain**
  - **Stability**
  - **Noise**

Review Questions:

- Consider the inverted pendulum shown in Figure El. 13. Sketch the block diagram of a feedback control

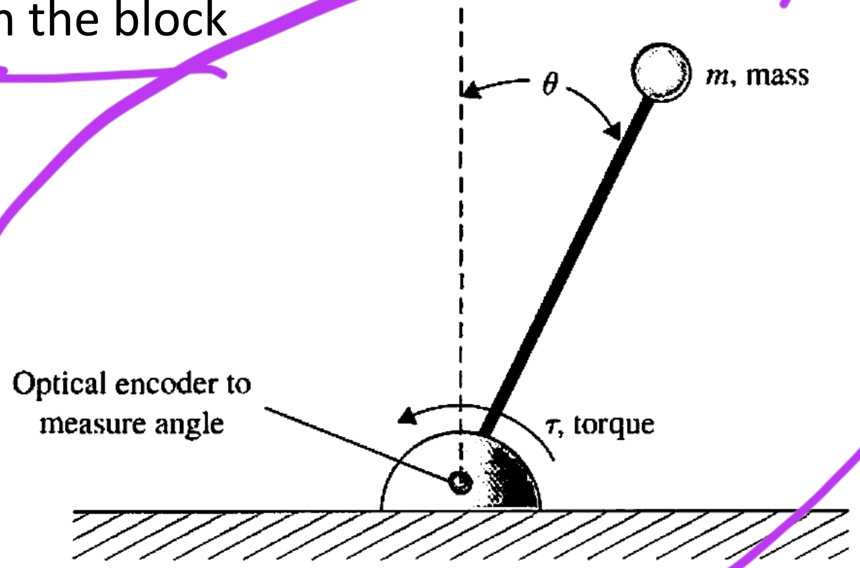
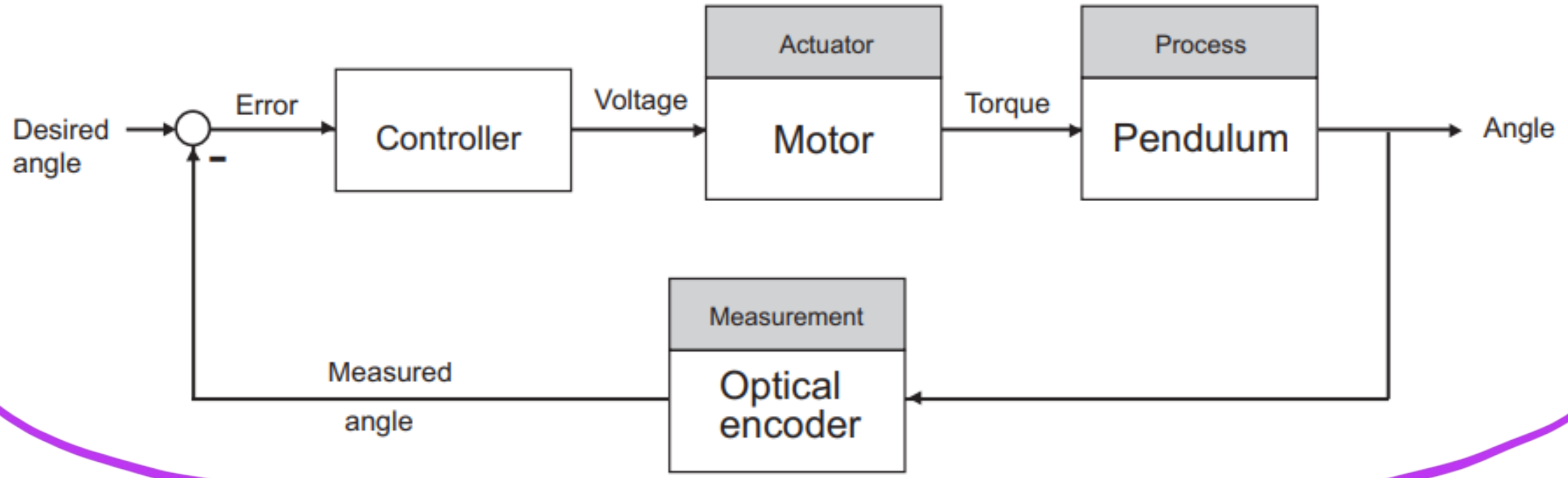


FIGURE E1.13 Inverted pendulum control.

Answer

Block Diagram

An inverted pendulum control system using an optical encoder to measure the angle of the pendulum and a motor producing a control torque:



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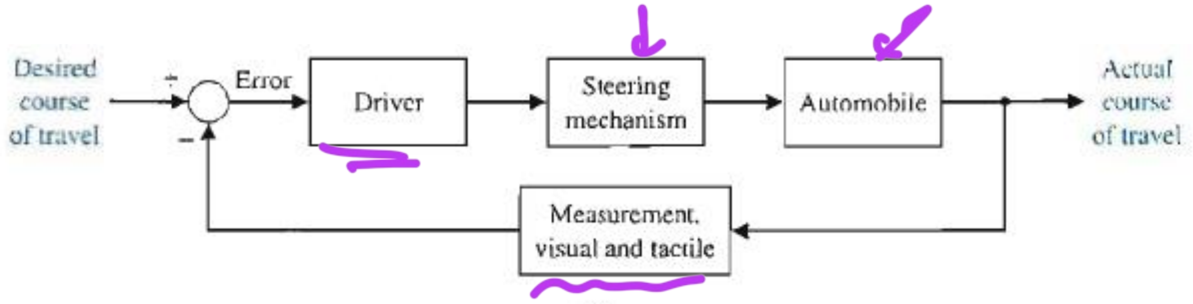
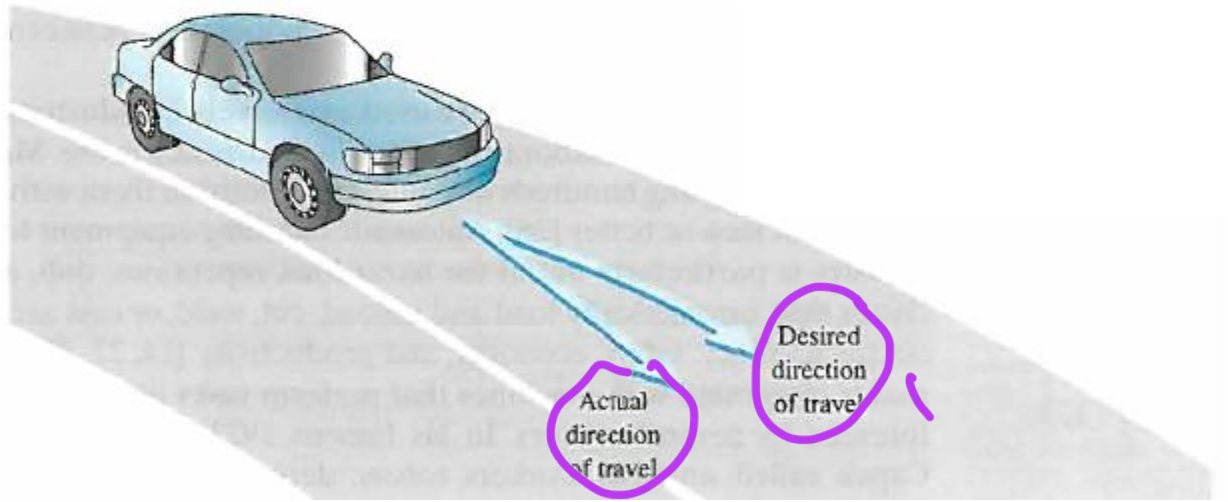
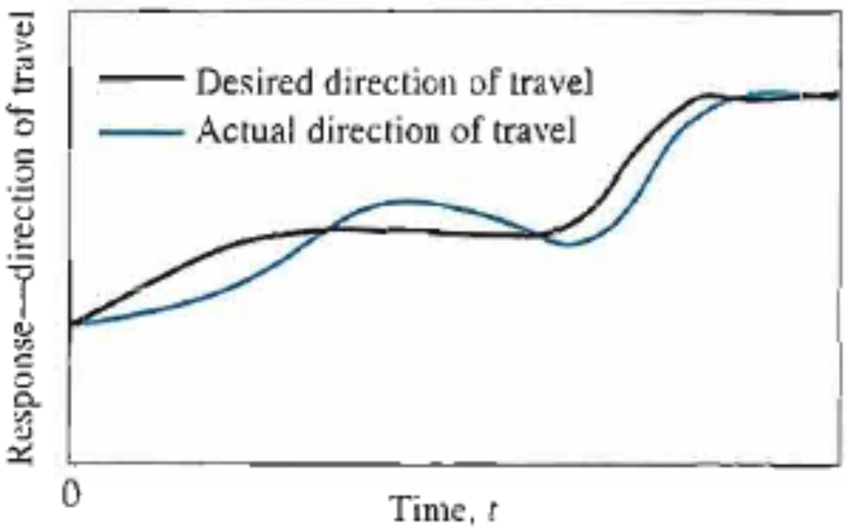
Example of feedback control system



(a)





(c)

▶ REVIEW QUESTIONS

1. List the advantages and disadvantages of an open-loop system.
2. List the advantages and disadvantages of a closed-loop system.
3. Give the definitions of ac and dc control systems.
4. Give the advantages of a digital control system over a continuous-data control system.
5. A closed-loop control system is usually more accurate than an open-loop system. (T) (F)
6. Feedback is sometimes used to improve the sensitivity of a control system. (T) (F)
7. If an open-loop system is unstable, then applying feedback will always improve its stability. (T) (F)
8. Feedback can increase the gain of a system in one frequency range but decrease it in another. (T) (F)

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- **Feedback is an essential aspect of control systems and has many applications in various fields of engineering.** Feedback is a process in which the output of a system is fed back to its input, either directly or through some other component of the system. This feedback loop allows the system to adjust its output based on certain criteria, such as the desired setpoint or the error between the actual output and the setpoint. In this way, feedback can be used to improve the performance of a system, reduce its error, and make it more stable.

- **Statement 1: The effect of feedback is to reduce the system error.** The statement is correct. Feedback can be used to reduce the system error and improve its performance. By measuring the error between the output and the setpoint, and adjusting the input accordingly, feedback can help to minimize the error and bring the system closer to the desired setpoint. This is achieved by using a controller that compares the actual output to the setpoint and generates a control signal that adjusts the input to the system.

- **Statement 2: Feedback increases the gain of the system in one frequency range but decreases in another.** The statement is correct. Feedback can affect the gain and stability of a system in different frequency ranges. In some cases, feedback can increase the gain of the system in a particular frequency range, while in other cases, it can decrease the gain and destabilize the system. This is due to the fact that feedback introduces a phase shift in the system's response, which can interact with the system's natural frequency and cause resonance or instability.

- **Statement 3: Feedback can cause a system that is originally stable to become unstable.** The statement is correct. Feedback can cause a stable system to become unstable if the gain and phase shift introduced by the feedback loop are not properly tuned. This can lead to instability, oscillations, and even system failure. Therefore, it is important to design feedback systems that are stable and robust, and to ensure that the gain and phase margins are sufficient to prevent instability.

Exercises

1. A physical system is a collection of ___________ connected together.
2. An idealized physical system is called a __________.
3. The mathematical representation of the __________ is called the mathematical model.
4. Based on the hierarchy, control systems may be classified as (i) __________ (ii) _________ (iii) __________ (iv) __________ and (v) ____________.
5. Based on the presence of human being as part of the system, control systems may be classified as (i) ___________ and (ii) ___________.
6. Depending on the presence of feedback, control systems may be classified as (i) ___________ and (ii) ___________.
7. Based on the main purpose of the system, control systems may be classified as (i) ___________ (ii) ___________ (iii) _____________, etc.
8. According to the method of analysis and design, control systems may be classified as (i) ___________ and (ii) ___________.
9. Depending on whether the parameters of the system remain constant or vary with time, control systems may be classified as (i) ___________ and (ii) ___________.
10. According to the type of signals used in the system, control systems may be classified as (i) ___________ and (ii) ___________ or (i) ___________ and (ii) ___________.

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Answers to Fill in the Blanks

1. physical objects **2.** physical model **3.** physical model **4.** (i) open-loop control systems, (ii) closed-loop control systems, (iii) optimal control systems, (iv) adaptive control systems, (v) learning control systems **5.** (i) manually controlled systems, (ii) automatic control systems **6.** (i) open-loop control systems, (ii) closed-loop control systems **7.** (i) position control systems, (ii) velocity control systems, (iii) traffic control systems, etc. **8.** (i) linear control systems, (ii) nonlinear control systems **9.** (i) time-varying control systems, (ii) time-invariant control systems **10.** (i) continuous-data control systems, (ii) discrete-data control systems, or (i) ac control systems, (ii) dc control systems **11.** (i) position control systems,

Thank You